

# Ultrasound effect on electrospark cementation process

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**Abstract.** The process of carburizing is well-studied and is one of the traditional processes of the thermochemical treatment of steel. The process has disadvantages such as high energy consumption, long exposure time, complicated processing of large products and surfaces. Electrospark deposition with a carbon electrode is proposed as an alternative process. The carburizing extent and the working layer depth can be increased when the process is used in the ultrasonic vibration field. A resonant vibration introducing circuit with a standing wave generated in the specimen tested is implemented to identify the influence of specific ultrasonic wave areas on the hardened layer formed. The highest carbon saturation of the surface layer was found in the standing ultrasonic wave oscillation node area, where cyclic stretching and compression of the medium contribute to the excess phases release. The carbon in the martensite estimated by the  $c/a$  ratio was 0.78% by weight. The highest cementite layer depth and transition zone size are in the ultrasonic wave antinode area, where the highest dynamic medium particles displacement is observed under the influence of vibrations. It is shown that the base metal structure component dispersiveness is responsible for the increased hardened layer depth.

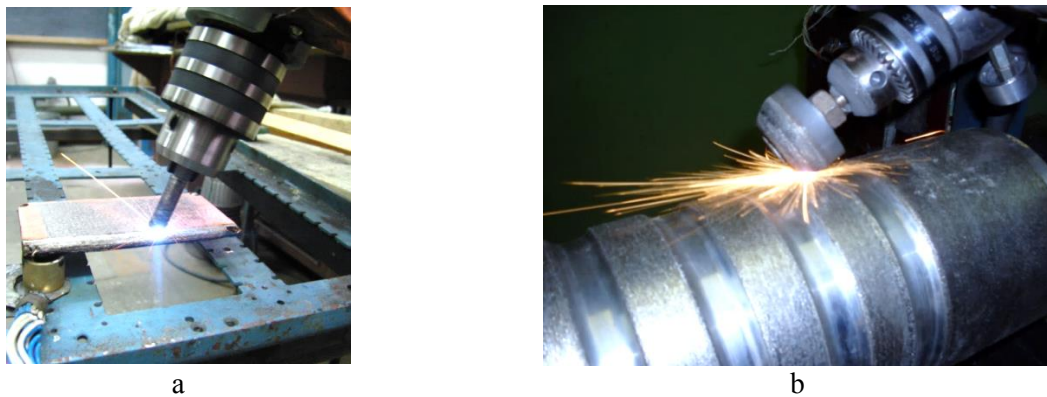
## 1. Introduction

Carburizing is commercially used to increase the hardness and wear resistance of the surface while retaining their core toughness [1]. Solid carburizing, liquid carburizing and gas carburizing [1 to 3] are conventional well-studied methods and, despite their wide-spread extent, have a number of big disadvantages: process duration, high temperature [4, 5], resulting in the austenite growth, and therefore additional heat treatment is needed [6 to 8]. Thermochemical treatment of large parts and forming tools [9] is also highly complicated in terms of technology.

Recent attempts to obtain a cementite layer on the surface of parts use a spark discharge [10 to 14]. They are based on the electrospark deposition process (EDP) (Figure 1) whereby the spark discharge destroys the anode and its erosion materials transfer to the cathode (a part under treatment) [15, 16].

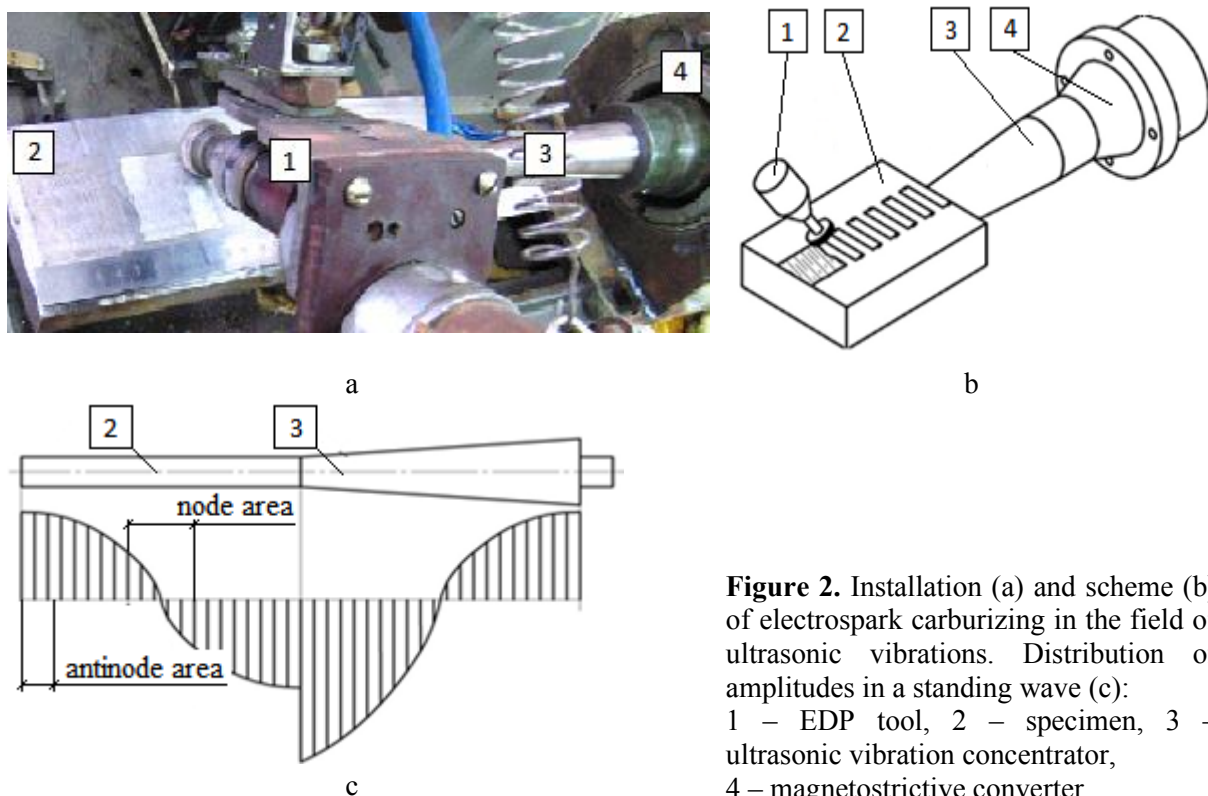
The high discharge temperature causes the electrode material particles to melt and partially evaporate. The material vapors expand and remove from the surface the particles of the anode, which passes through the gas medium, penetrates the cathode and generates a hardened layer. The cathode zone under the spark discharge also heats up suddenly and cools down immediately down due to the heat pickup. Thus, the surface is quenched increasing the hardness.





**Figure 1.** Electrospark depositing of a flat part (a) and a cylindric part (b).

The of electrospark carburizing method significantly reduces the power capacity of the process and improves the productivity. Unlike the conventional process not long exposure at high temperatures gives no rise to the austenite growth. Although this method looks interesting, the cementite layer is not deep enough and low extent of cementation.



**Figure 2.** Installation (a) and scheme (b) of electrospark carburizing in the field of ultrasonic vibrations. Distribution of amplitudes in a standing wave (c): 1 – EDP tool, 2 – specimen, 3 – ultrasonic vibration concentrator, 4 – magnetostrictive converter.

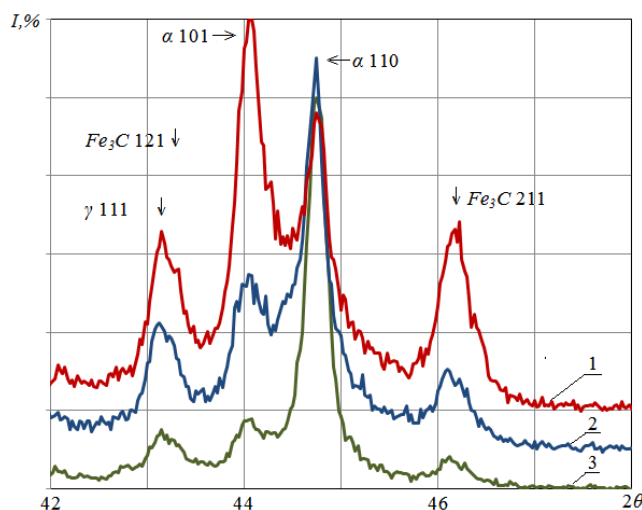
## 2. Material, processing and preparation of specimens

This study is intended to intensify diffusion processes of electrospark carburizing with ultrasonic vibrations (UV). A resonant circuit was used to identify a specific ultrasonic vibration in the areas of nodes and frequency antinodes. This method has proven itself well in the study of the ultrasound effect on the surfaced coating formation and was implemented in our studies [17 to 19]. The size of the plates is corresponded to the sound wavelength ( $\lambda$ ) in low-carbon steel (Figure 2). A standing ultrasonic wave was generated in the specimen with a frequency of 18 kHz and a calculated amplitude of 12.6 microns.

The test specimens were cut out of a plate from the node and standing wave antinode area (Figure 2). The base metal i.e. a '20' steel plate was heat treated in three ways: annealing (cooling inside furnace), normalization (forced air blowing), quenching (cooling in a spray device for rapid cooling). The carbon was determined in the surface layer by a Bruker Q2 ION optic emission spectrometer; the structure was investigated with a Phenom G2 Pure scanning electron microscope; hardness distributed through the layer depth was investigated with a FutureTechFM-300 automatic microhardness tester. A Bruker D8 Advance x-ray diffractometer was used for phase X-raying with K-rays  $\alpha$  Cu in  $\theta$ -geometry by step scanning in the angle range  $2\theta = 30 - 140^\circ$ .

### 3. Research results

The phase analysis of the hardened layers showed the maximum influence of ultrasonic vibrations in the areas near the standing wave vibrations node. The intensity of cementite and austenite lines increases greatly, and the martensitic doublet is well detected (Figure 3). The carbon content of martensite estimated by the  $c/a$  ratio, was 0.78% by weight.



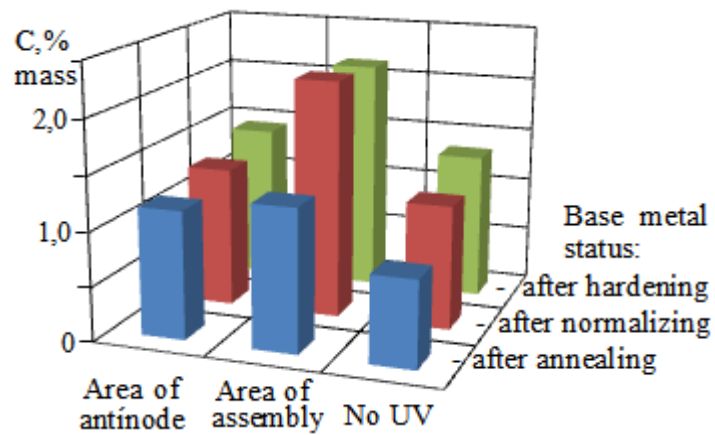
**Figure 3.** Cementite layer diffractogram sectors (at the node (1), antinode (2) of standing wave oscillations, without ultrasonic vibrations (3)).

As expected, the lowest cementation was obtained for the specimens without ultrasonic influence, on the basis of annealed steel and after normalization (0.80 and 1.15 % C), respectively (Figure 4). Ultrasonic vibrations increase the carbon content in the hardened layer, and it is the most in the area of cyclic stretching and contraction of the medium (i.e. at the node of oscillation of the standing wave). The highest cementation was achieved on the base metal after normalization and quenching (2.20 and 2.15 % C). The average carbon in the cementite layer of the specimens cut from the standing wave region is also higher and is 1.2% to 1.4%.

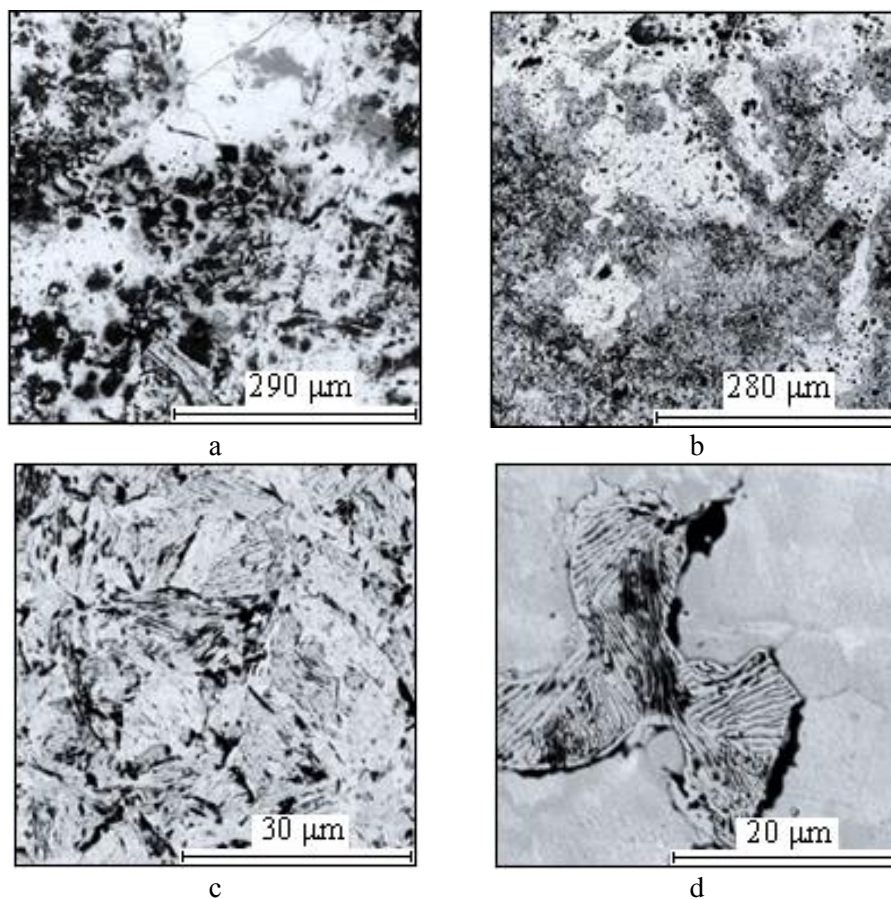
The layer depth is a key cementation parameter, which can be approximately determined on inclined sections. The layer depth values have a high measurement error due to some specific qualities of the EDP process technology and of the hardened layer structure.

Metallographic studies have shown that four characteristic zones can be distinguished on the surface of the specimen subjected to EDP cementation: 1 – upper zone, fragmented coating with higher coarseness (Figure 5, a); 2 – white solid (non-etching) layer; 3 – transition layer (Figure 5, b); 4 – base metal (Figure 5, c, d).

After processing the layer depth data obtained by direct measurement, it was found that the layer is minimal with electrosark cementation without ultrasonic vibrations i.e.  $0.06 \pm 0.02$  mm. One may note that the depth increases when the state of the base metal changes from annealed to hardened, although it is close to the limit of statistical error. The ultrasonic influence increases the coating deeper up to  $0.10 \pm 0.02$  mm, and it is higher in the antinode than in the node.

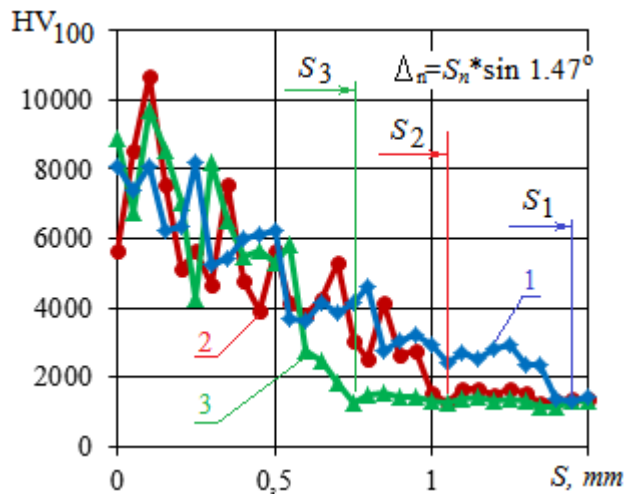


**Figure 4.** Average carbon in the hardened layer (% of mass) in the representative sectors of the standing ultrasonic wave with different workpiece thermal treatment methods.



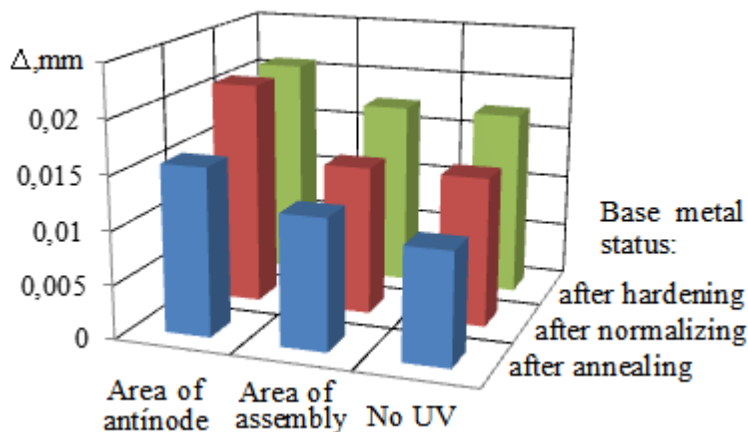
**Figure 5.** Hardened layer structure (inclined polish sections):  
a – fragmented coating; b – diffusion layer. Base metal: c – after quenching; d – after annealing.





**Figure 6.** Distribution of microhardness through the depth of the hardened layer (measured on inclined polished section): 1 – antinode area; 2 – vibration node area of a standing ultrasonic wave; 3 – No UV. Preliminary thermal treatment of the backing is normalization. The dotted line indicates the transition to the base metal.

The degree of development of diffusion processes can be estimated by the length of the transition zone  $\Delta$ , mm (Figure 6). Parameter values  $\Delta$  are maximal in the sectors of the standing wave antinode and increase when the backing structural components diminish. The transition zone extension reaches its maximum (up to 0.02 mm) when the specimens are electrospark-carburized after normalization and quenching. In the vibration node and during the process without ultrasonic vibrations the values are close and are 0.017 and 0.014 mm respectively (Figure 7).



**Figure 7.** Cementation layer transition zone size  $\Delta$  (mm).

#### 4. Conclusion

Thus, the electrospark cementation is effective for surface treatment of large products and, unlike the conventional thermochemical treatment, is of finishing type. The hardened layer qualities (cementation extent and depth) can be improved when processing in the ultrasonic vibrations field. The resonant circuit used in the experiment made possible to determine the influence of the representative areas of the standing ultrasonic wave on the cementite layer qualities. The highest cementation was found in the standing ultrasonic wave vibration node area, where cyclic stretching and compression contribute to the excess phases increase. The diffusion processes that determine the cementite layer depth and transition zone size are in their turn maximum in the ultrasonic wave antinode area, where the highest dynamic medium particles offset is observed under the influence of vibrations. The base metal structure component dispersiveness is responsible for the increased hardened layer depth. It reaches  $0.10 \pm 0.02$  mm when combined with ultrasonic exposure for specimens after normalization and quenching.

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